National Aeronautics and Space Administration

Future of Space Communications

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Space Generation Congress 2012 - Naples

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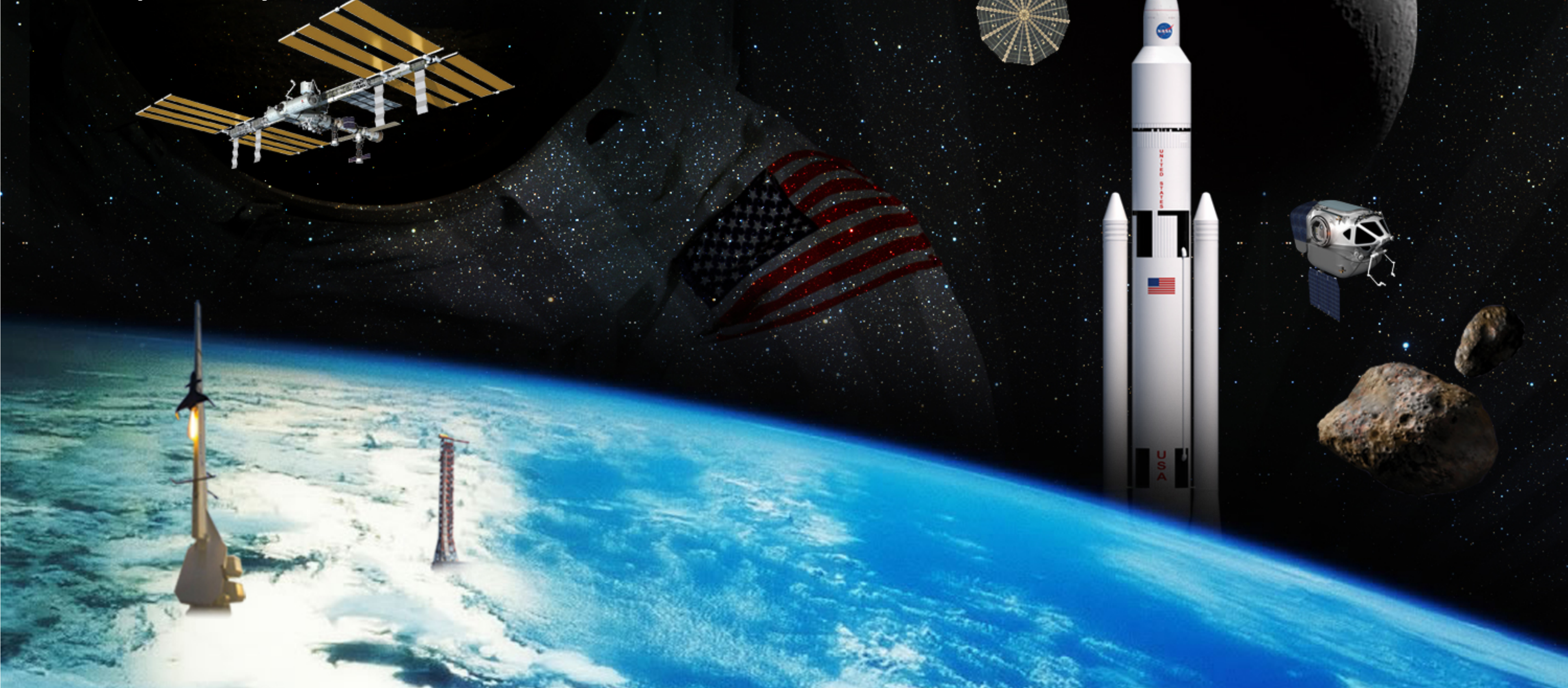
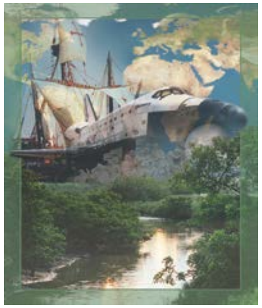
Naples, Italy



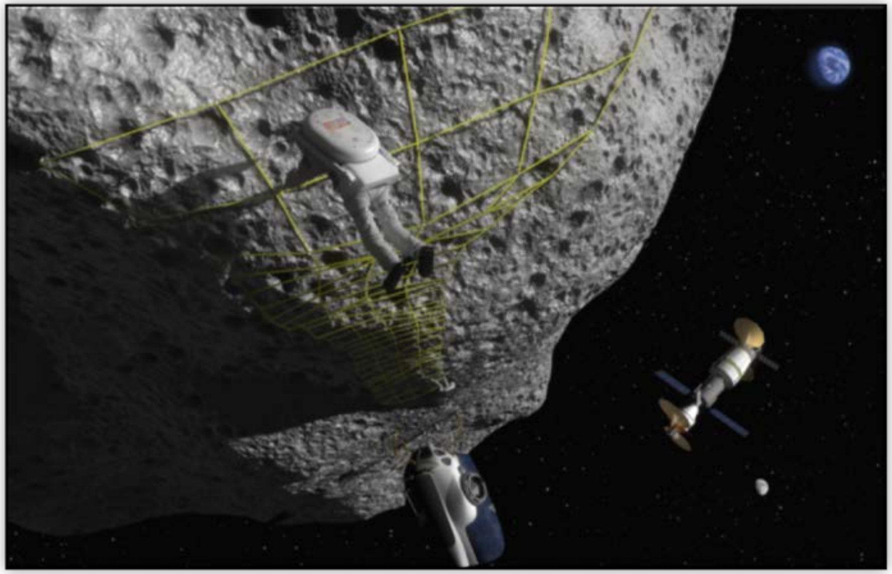
Agenda

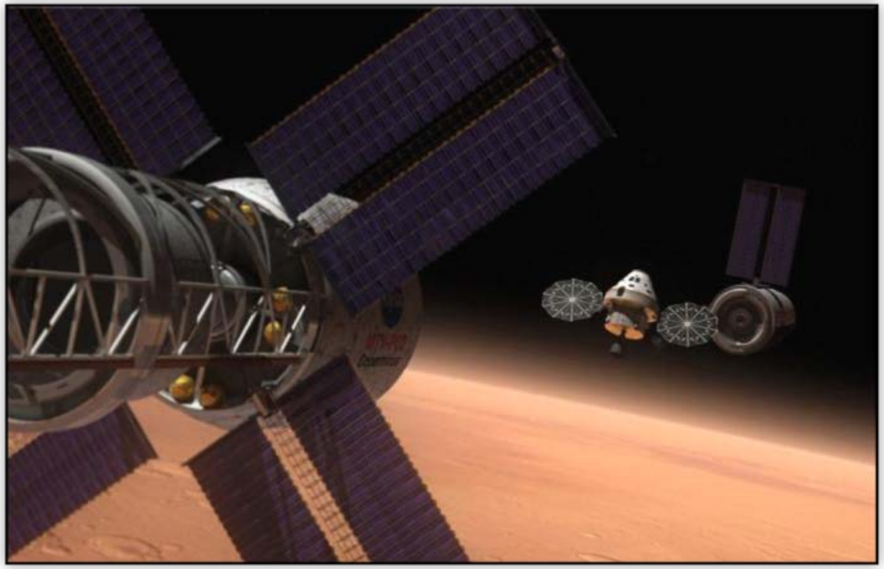
- Exploration: The Past and Present
- Background: Network Evolution
- Technology Initiatives
  - Optical Communications
  - SCaN Testbed
  - Disruption Tolerant Networking and Software Defined Radio
  - Navigation
- Future of Human Spaceflight
- International Cooperation
- Summary

Exploration, Not Long Ago



Exploration, Continuing the Journey
Multiple Destinations with Next-Generation Technologies





BACKGROUND:
NETWORK EVOLUTION

SCaN Current Networks

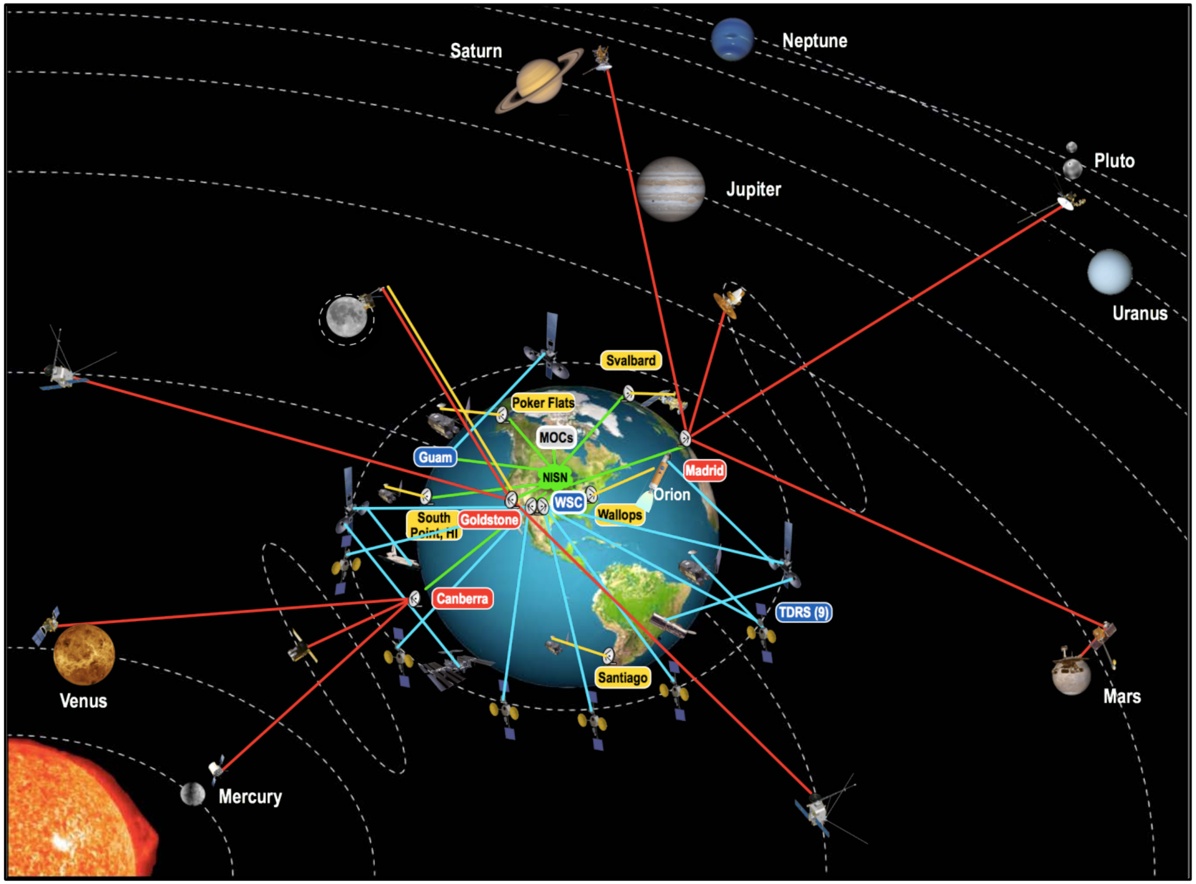
The current NASA space communications architecture embraces three operational networks that collectively provide communications services to supported missions using space-based and ground-based assets.

Near Earth Network – NASA, commercial, and partner ground stations and integration systems providing space communications and tracking services to orbital and suborbital missions

Space Network – constellation of geosynchronous relays (TDRSS) and associated ground systems

Deep Space Network – ground stations spaced around the world providing continuous coverage of satellites from Earth Orbit (GEO) to the edge of our solar system

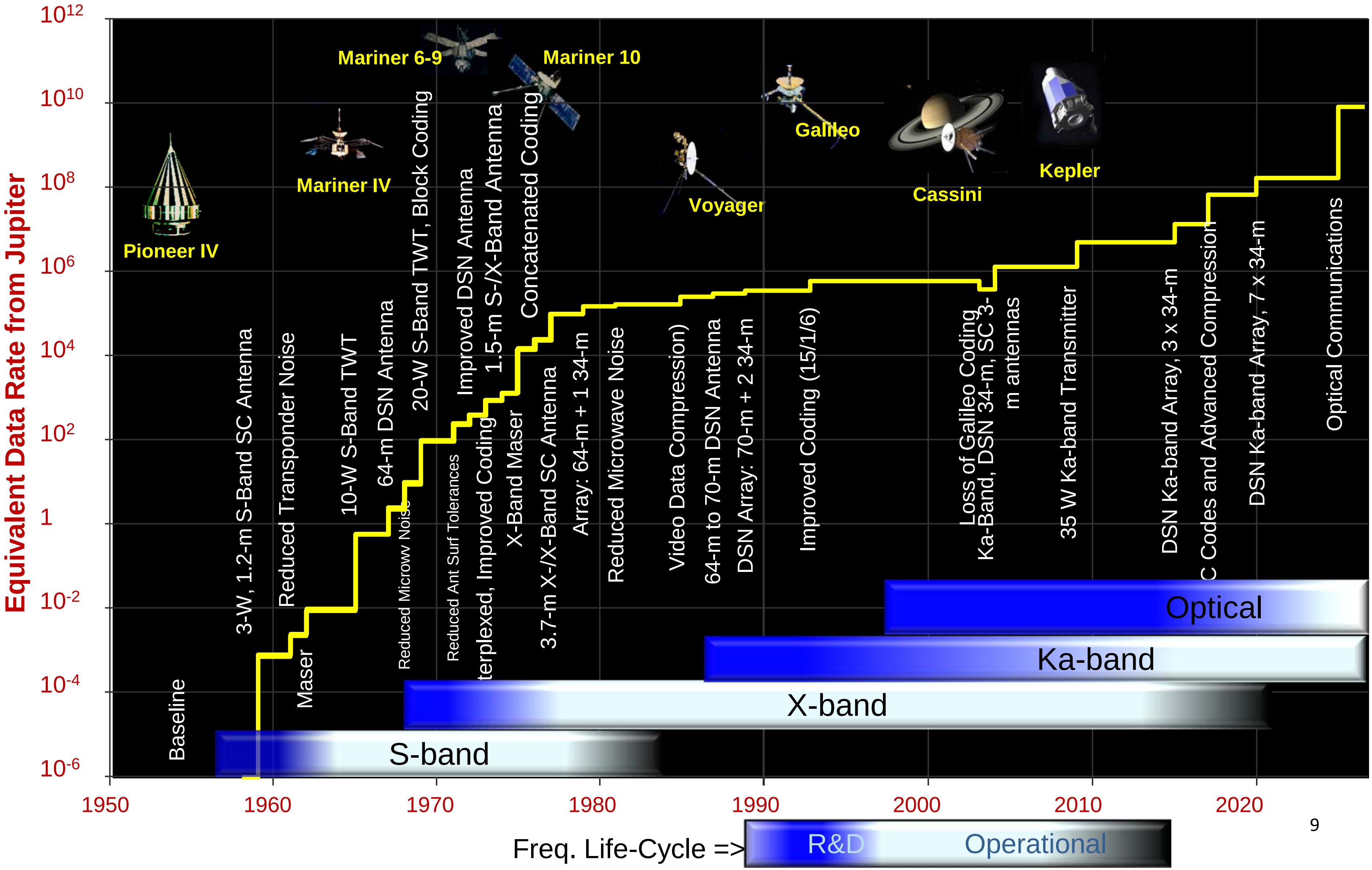
NASA Integrated Services Network (NISN) – no longer part of SCaN; provides terrestrial connectivity



SCaN Network

TECHNOLOGY INITIATIVES

Data Rate Evolution



Benefits of Optical Communications?

Depending on the mission application, an optical communications solution could achieve…

- **~ 50% savings in mass**
  - Reduced mass enables decreased spacecraft cost and/or increased science through more mass for the instruments
- **~ 65% savings in power**
  - Reduced power enables increased mission life and/or increased science measurements
- **Up to 20x increase in data rate**
  - Increased data rates enable increased data collection and reduced mission operations complexity

…over existing RF solutions

Mars Reconnaissance Orbiter (MRO) Example

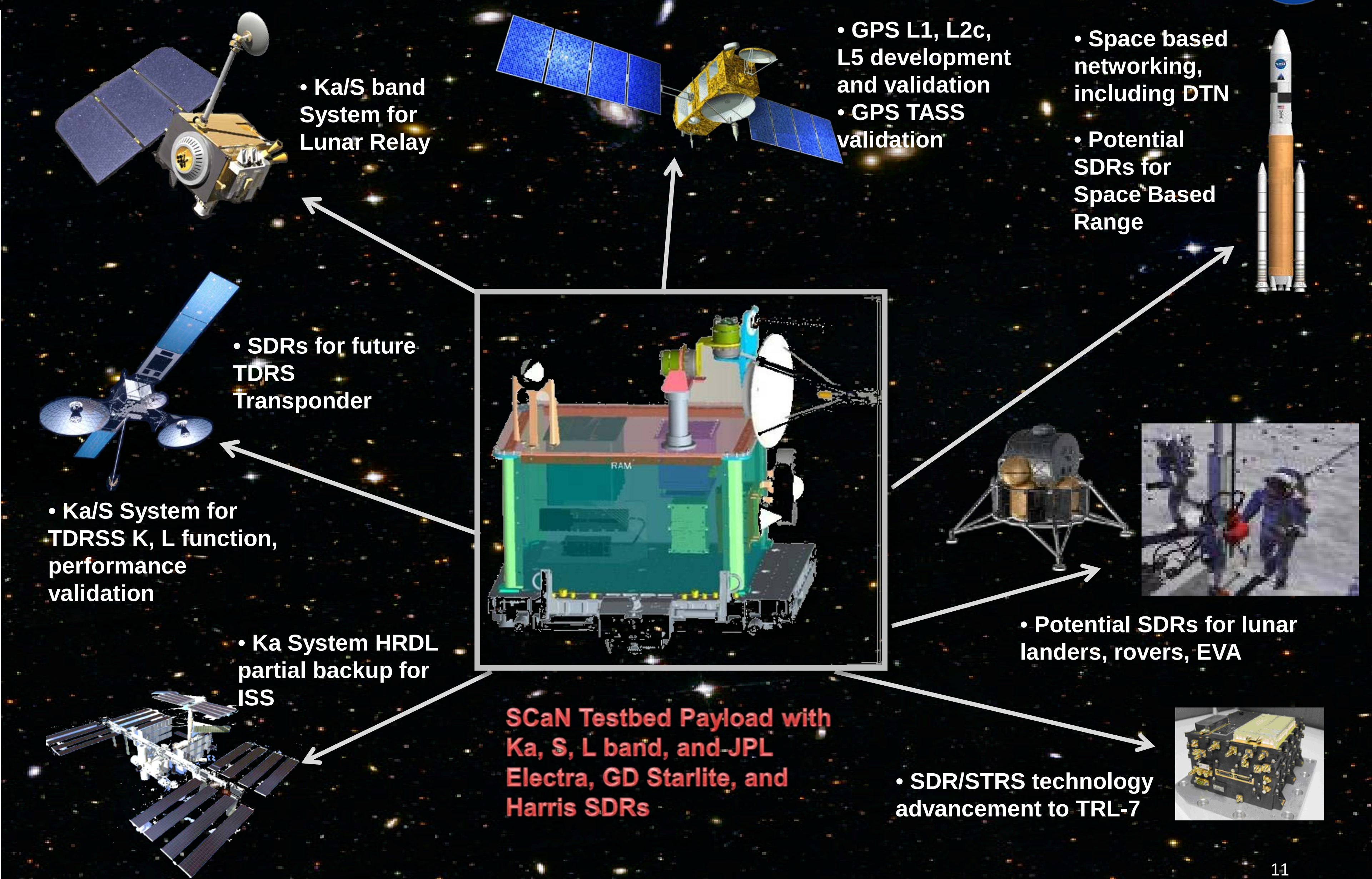
This image taken by the Mars Reconnaissance Orbiter represents what one could see from a helicopter ride at 1000 feet above the planet. While this mission is collecting some of the highest resolution images of Mars to date and it will collect 10 to 20 times more data than previous Mars missions, bandwidth is still a bottleneck.

Data collection for climate observations must be turned off while not over the poles because we cannot get the data back.

At MRO's maximum data rate of 6 Mbps (the highest of any Mars mission), it takes nearly 7.5 hours to empty its on-board recorder and 1.5 hours to transfer a single HiRISE image to earth.

In contrast, with an optical communications solution at 100 Mbps, the recorder could be emptied in 26 minutes, and an image could be transferred to earth in less than 5 minutes.

Benefits of the SCaN Testbed to NASA Programs and Missions

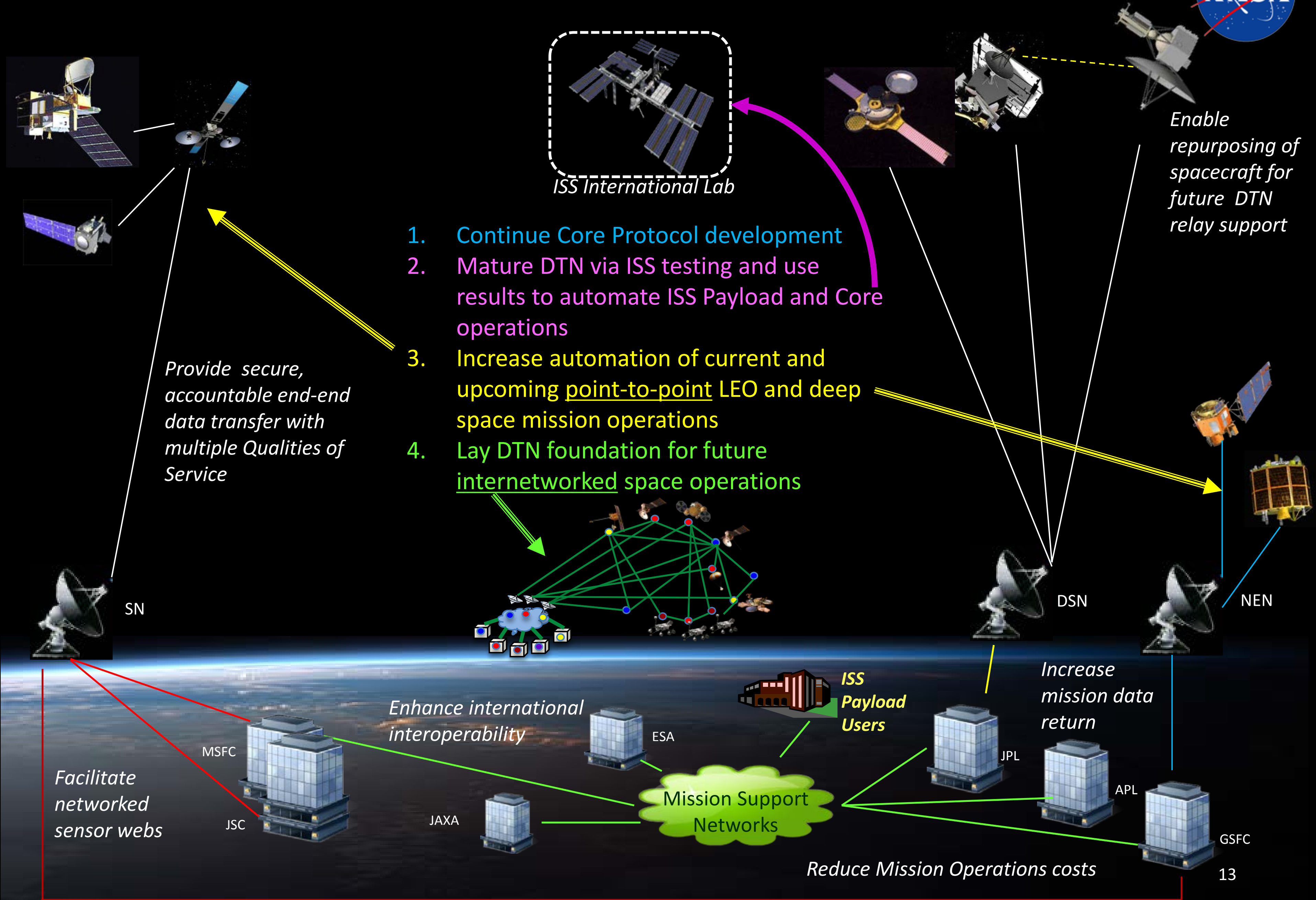


Why Use Software Defined Radios (SDR) ?

- **Unprecedented operational flexibility with software functionality that allows communications functions to be updated in flight**
  - Functions can be changed within the same SDR across mission phases
    - E.g., Range Safety functions in launch phase, mission ops functions in mission phase
  - Technology upgrades can be made in flight
    - E.g., modulation methods upgrades, new coding schemes
  - Failure corrections can be effected in flight
    - E.g., MRO corrected EMI problem with SW update in transit to Mars using the Electra SDR
- **Small size, weight, and power is achievable for all SDRs, especially mobile units (e.g., EVAs, rovers), similar to cell phones**
  - SDRs have excellent potential for miniaturization compared to conventional radios
- **Software defined functionality enables standard radios to be tailored for specific missions with reusable software**
  - Similar to PCs running standard programs like Word and Excel, standardization enables common hardware platforms to run common reusable software across many missions
  - Cost reductions are realized with common hardware architecture, reusable software and risk avoidance

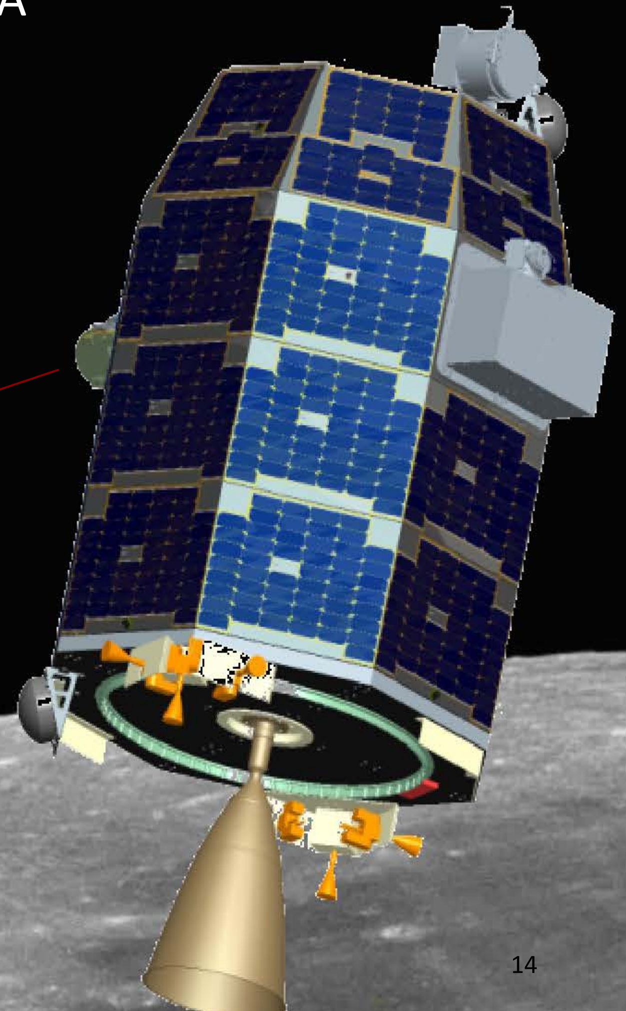
Disruption Tolerant Network (DTN)

1. Continue Core Protocol development
2. Mature DTN via ISS testing and use results to automate ISS Payload and Core operations
3. Increase automation of current and upcoming point-to-point LEO and deep space mission operations
4. Lay DTN foundation for future internetworked space operations

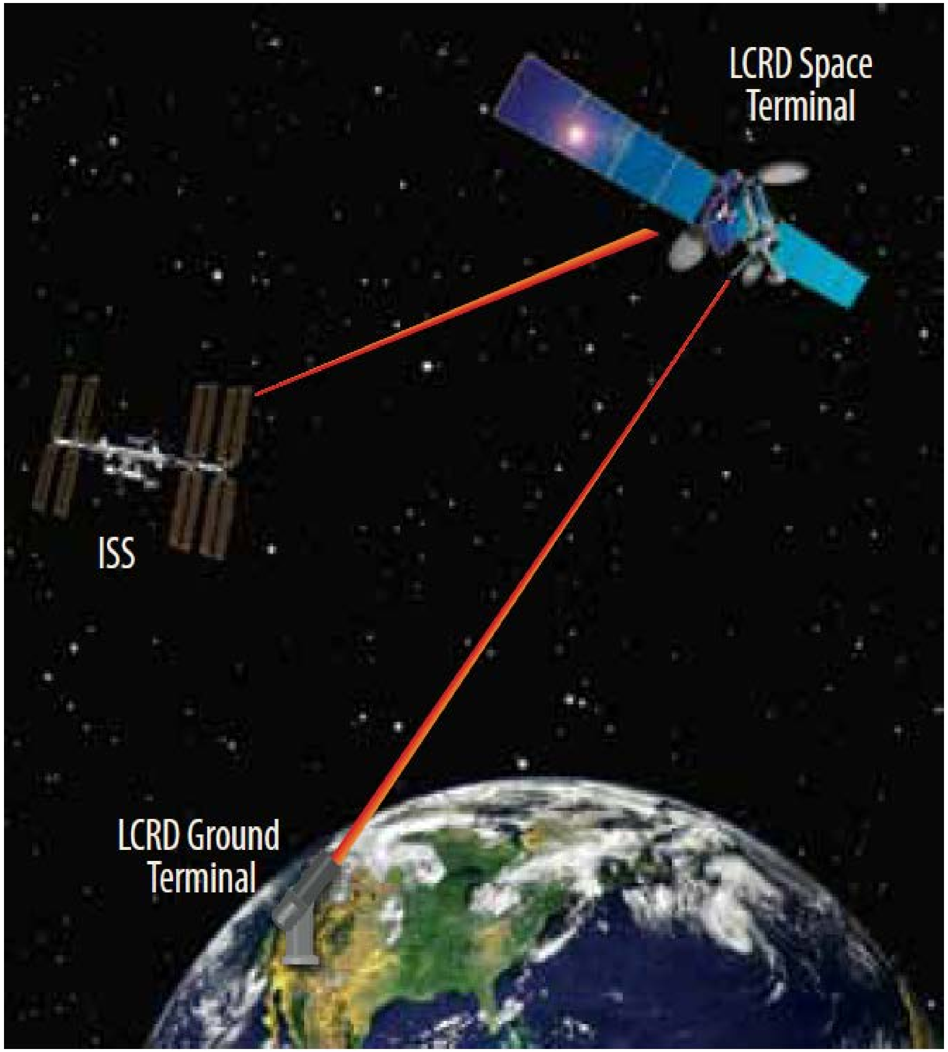


Lunar Laser Communications Demonstration

- Lunar Laser Communications Demo (LLCD) to fly on Lunar Atmosphere and Dust Environment Explorer (LADEE)
- Launch Readiness: 2013 from Wallops Flight Facility, VA on Minotaur V
  - 1 month transfer to the moon
  - 1 month commissioning
    - 250 km orbit around the moon
    - LLCD operation demonstrating 600 Mbps downlink
    - Spacecraft and science payloads checkout
  - 3 months science
    - 50 km orbit
    - 3 science payloads
      - Neutral Mass Spectrometer
      - UV Spectrometer
      - Lunar Dust Experiment



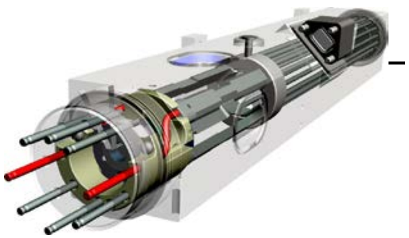
Laser Communications Relay Demo (LCRD)



- Will fly in 2017
- Demonstrate optical communication for the eventual inclusion in NASA's Next Generation Tracking and Data Relay Satellite (TDRS).
- A network node with two optical terminals based on the LLCD design.
- Data transfer will be at variable data rates up to 2.8 Gbps.
- Onboard processing will implement DTN protocols to help address atmospheric conditions.

Navigation and the Deep Space Atomic Clock

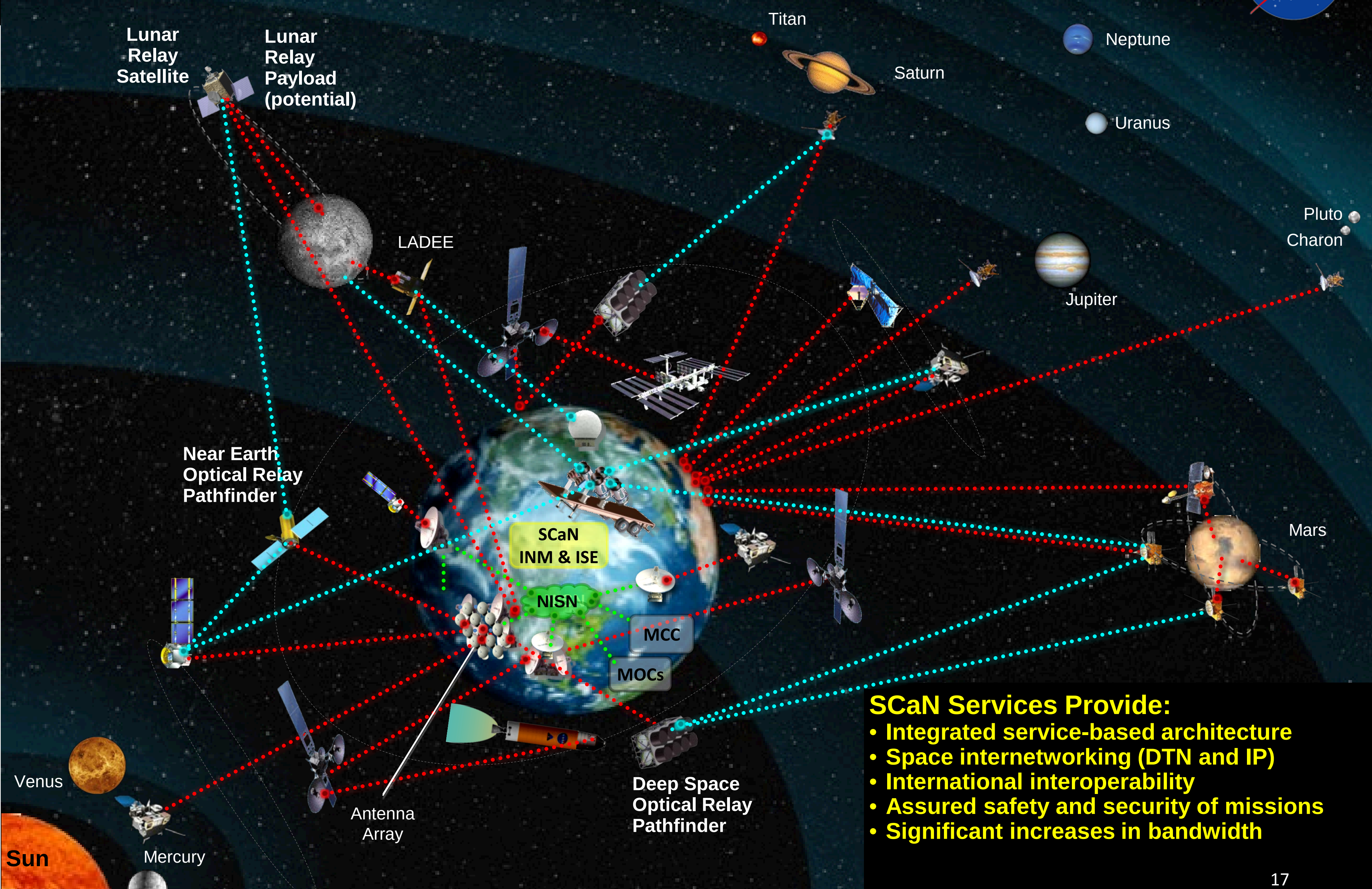
The Deep Space Atomic Clock (DSAC) is a single clock with excellent stability and medium to low relative SWAP for small spacecraft autonomous navigation.



- DSAC will revolutionize the way we conduct deep-space navigation by enabling a spacecraft to calculate its own timing and navigation data in real time.
  - One-way navigation technology will improve upon the current two-way system in which information is sent to Earth, requiring a ground team to calculate timing and navigation and then transmit it back to the spacecraft.
  - A real-time, on-board navigation capability is key to improving NASA's capabilities for executing time critical events, such as a planetary landing or planetary "fly-by," when signal delays are too great for the ground to interact with the spacecraft during the event.
  - Since frequency drift and accuracy can be compensated for, peak stability is the primary performance parameter for comparison, shown below as peak stability over an observation time, tau. Lower is better since it is a measure of deviation from optimal.

Clock Technology	Peak Stability (Allan Deviation)	Size	Mass	Power Consumption
ACES (clock ensemble)	10^-16 (expected in space test, tau = 1 day)	1 m^3	227 kg	450 watts
CSAC (chip clock)	10^-12 (short term, tau = 1 hr)	16 cm^3	35 g	115 milliwatts
JPL Space Clock (single Hg clock)	10^-15 (tau = 1 day)	.001 m^3	3 kg	10's of watts

SCaN Notional Integrated Communication Architecture



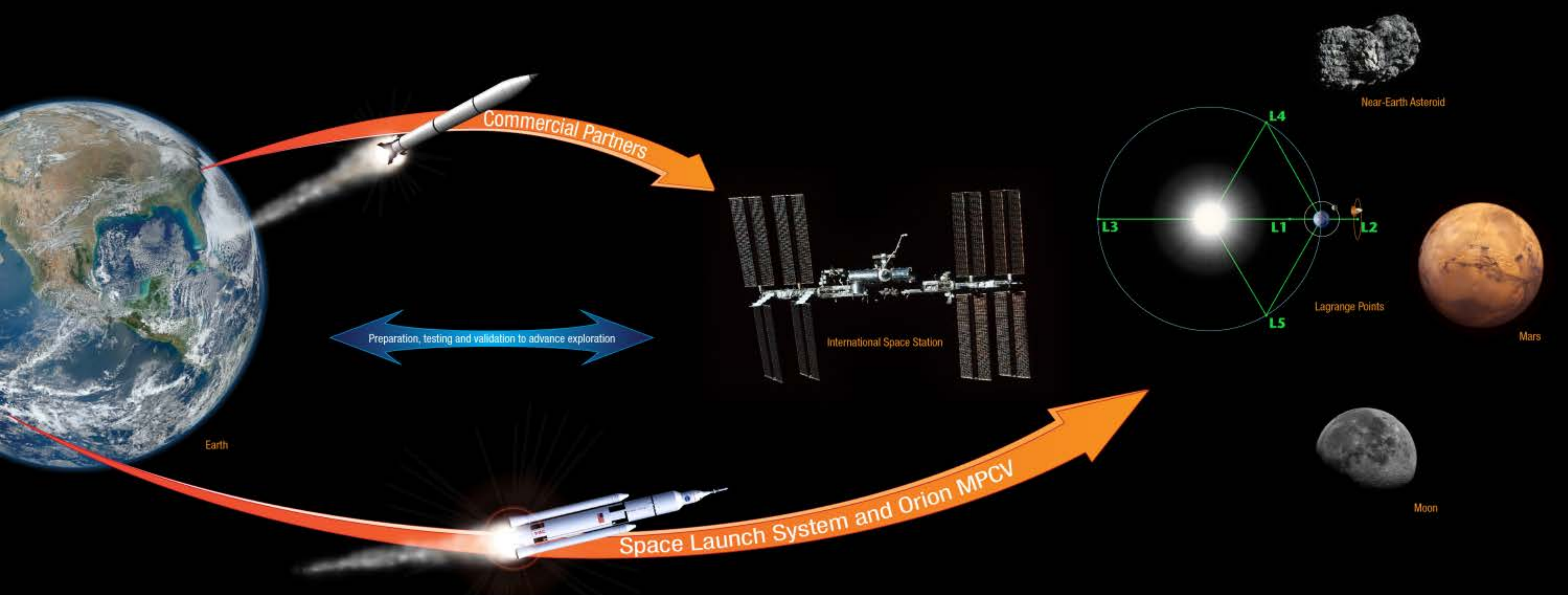
SCaN Services Provide:
- **Integrated service-based architecture**
- **Space internetworking (DTN and IP)**
- **International interoperability**
- **Assured safety and security of missions**
- **Significant increases in bandwidth**

Microwave Links | **Optical Links** | **NISN**

COMMUNICATIONS AND THE FUTURE OF HUMAN SPACEFLIGHT

The Future of American Human SPACEFLIGHT

National Aeronautics and Space Administration



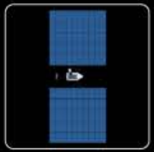
Human Spaceflight Capabilities

Mobile Extravehicular Activity and Robotic Platform

Deep Space Habitation

Advanced Spacesuits

Advanced Space Communication



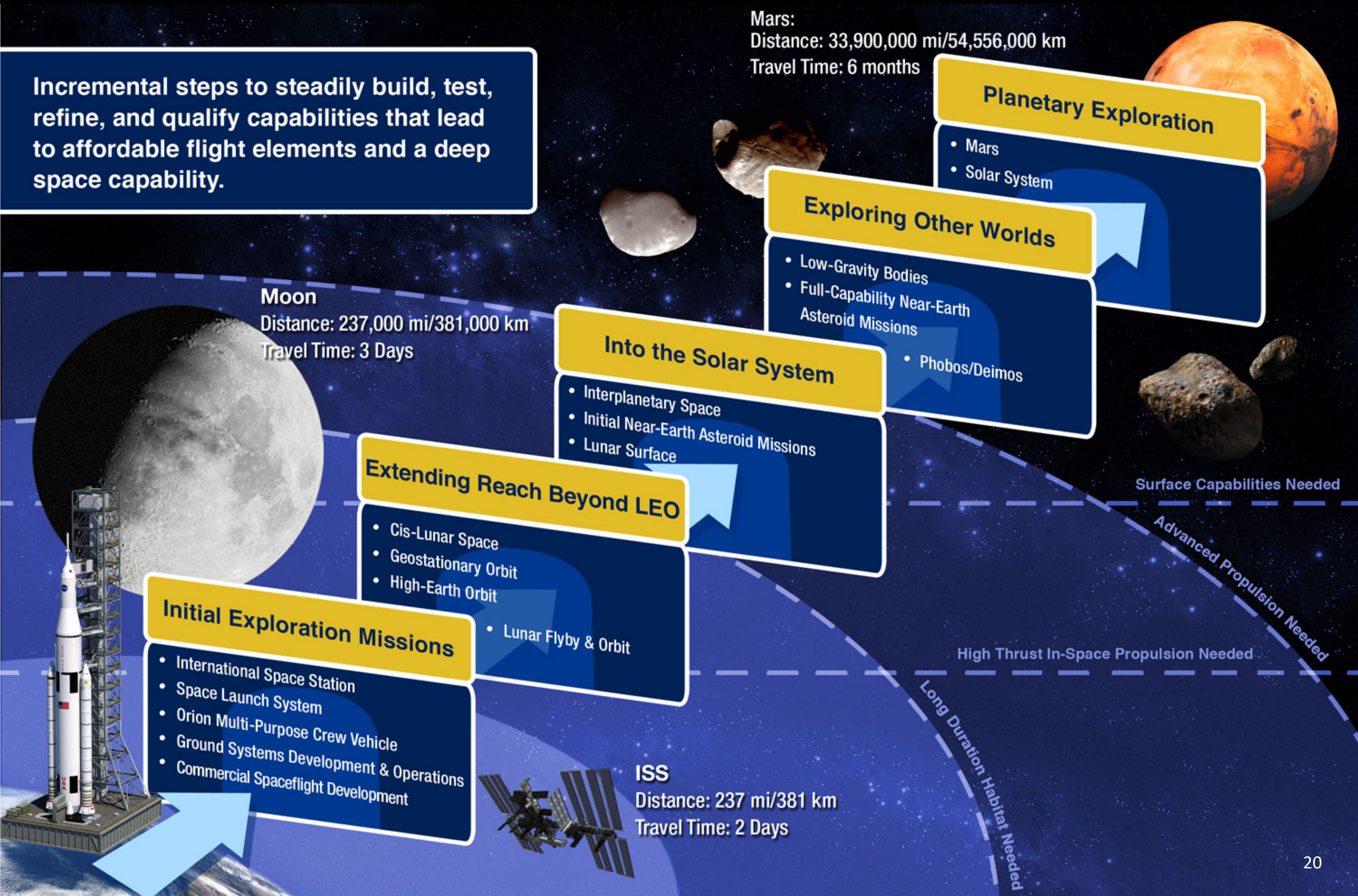
Advanced In-Space Propulsion

In Situ Resource Utilization

Human-Robotic Systems

Capability Driven Human Space Exploration

Incremental steps to steadily build, test, refine, and qualify capabilities that lead to affordable flight elements and a deep space capability.

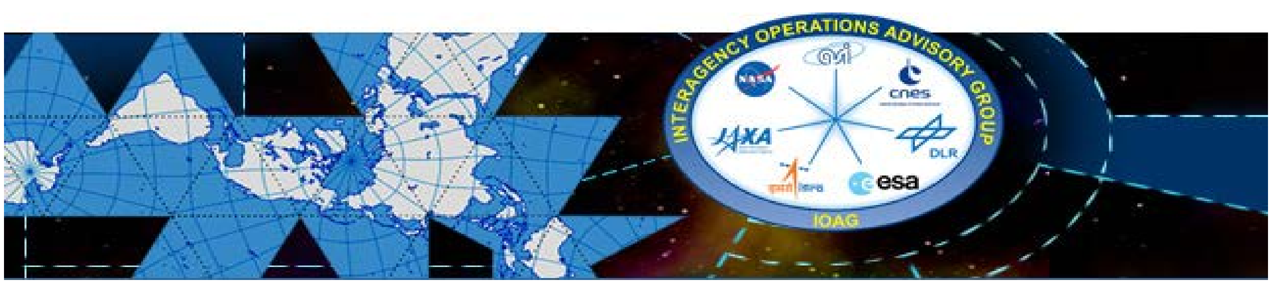


SPACE COMMUNICATIONS AND INTERNATIONAL COOPERATION

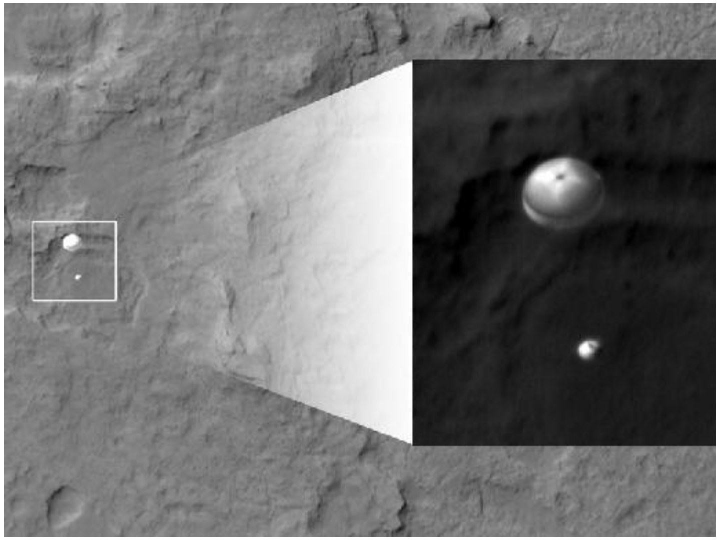
Enabling International Collaboration

SCaN represents NASA at international fora related to space communications and navigation issues. These include:

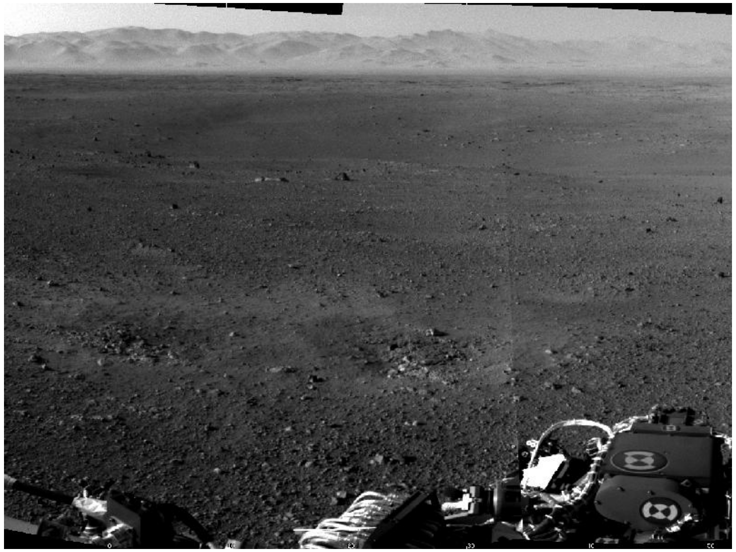
- Interoperability Plenary (IOP)
- Interagency Operations Advisory Group (IOAG)
- Space Frequency Coordination Group (SFCG)
- Consultative Committee for Space Data Systems (CCSDS)
- International Telecommunications Union (ITU)
- International Committee on Global Navigation Satellite Systems (ICG)
- Other Space Agencies



Exploration, Recently and Ongoing



Tracks left by NASA's Curiosity rover on August 22, as it completed its first test drive on Mars.



First two full-resolution images of the Martian surface from NASA's Curiosity rover

Curiosity's Seven Minutes of Terror

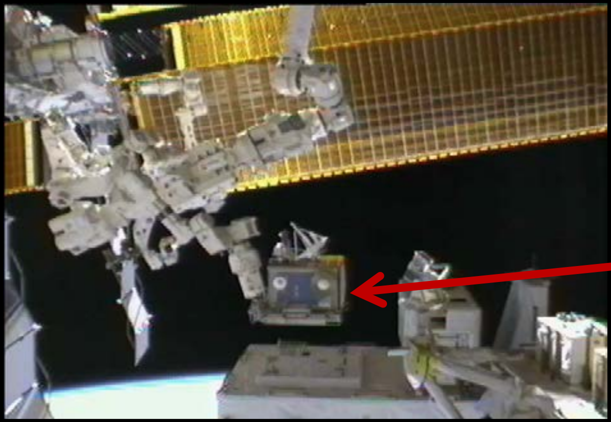
Summary

- Space Communications is a necessary component in all space activities – Without it, your spacecraft is space junk!

- SCaN is committed to developing the future space communication networks to fit the needs of NASA missions – to the Moon, Mars, and Beyond

- International cooperation and coordination of each country’s communication assets is vital for success

Thank You!



The Face of SCaN Testbed:
Gritty Smile, Jaunty Hat . . .
SCaN Bob Test Pants !!!

For more information visit NASA:

www.nasa.gov

or

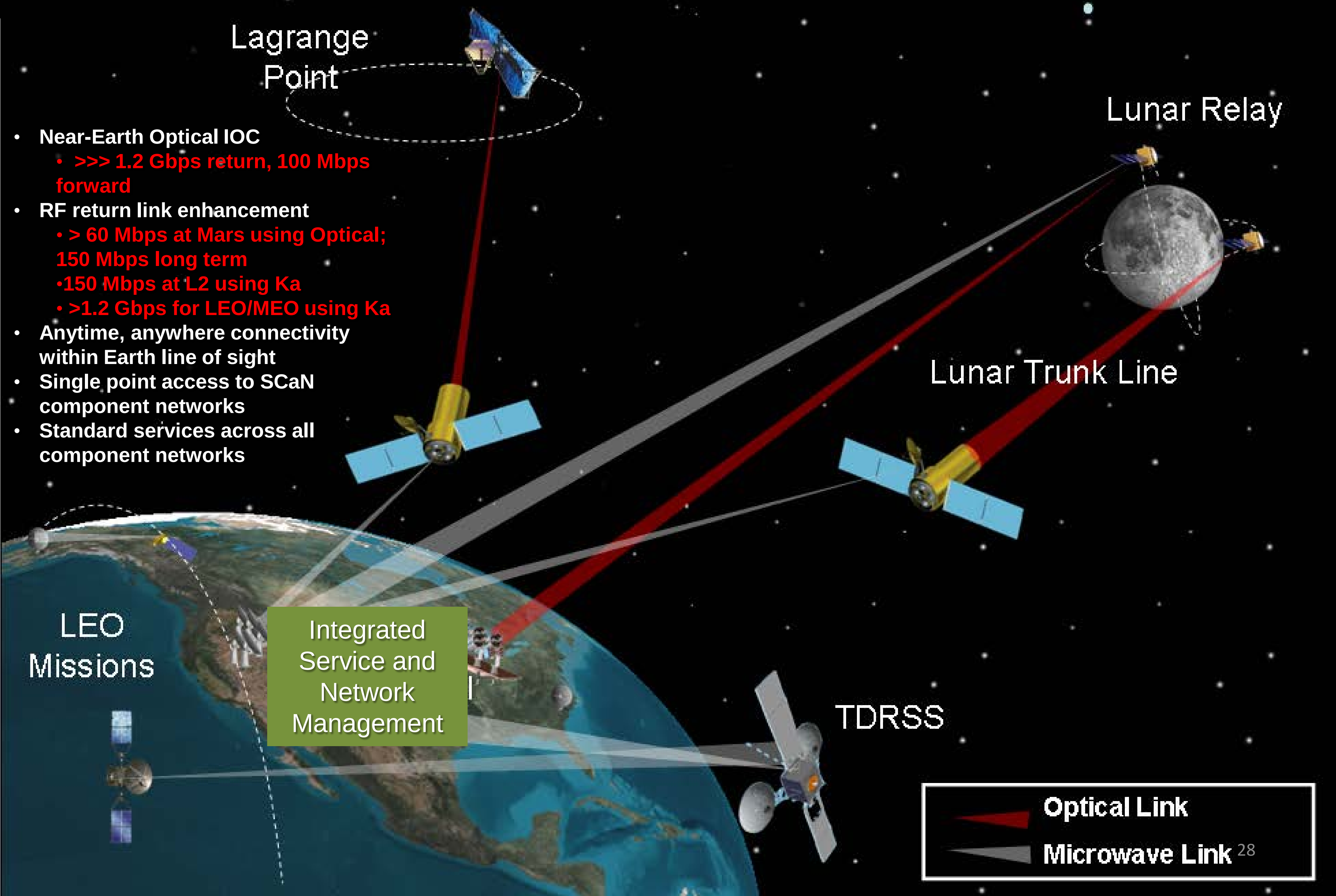
Space Communications and Navigation (SCaN):

www.spacecomm.nasa.gov

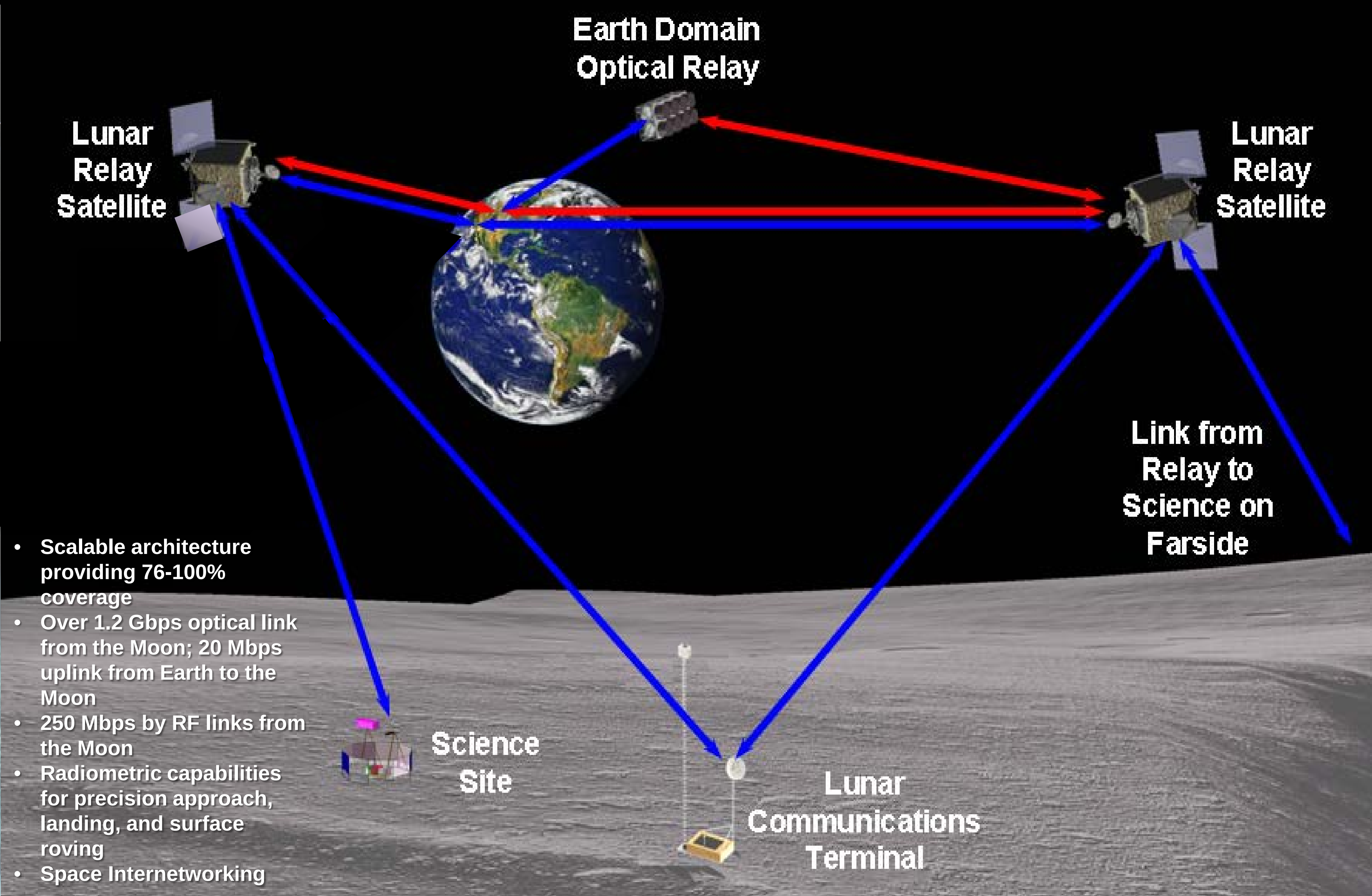
BACKUP

Enhanced Earth Domain Capabilities

- Near-Earth Optical IOC
  - >>> 1.2 Gbps return, 100 Mbps forward
- RF return link enhancement
  - > 60 Mbps at Mars using Optical; 150 Mbps long term
  - 150 Mbps at L2 using Ka
  - >1.2 Gbps for LEO/MEO using Ka
- Anytime, anywhere connectivity within Earth line of sight
- Single point access to SCaN component networks
- Standard services across all component networks

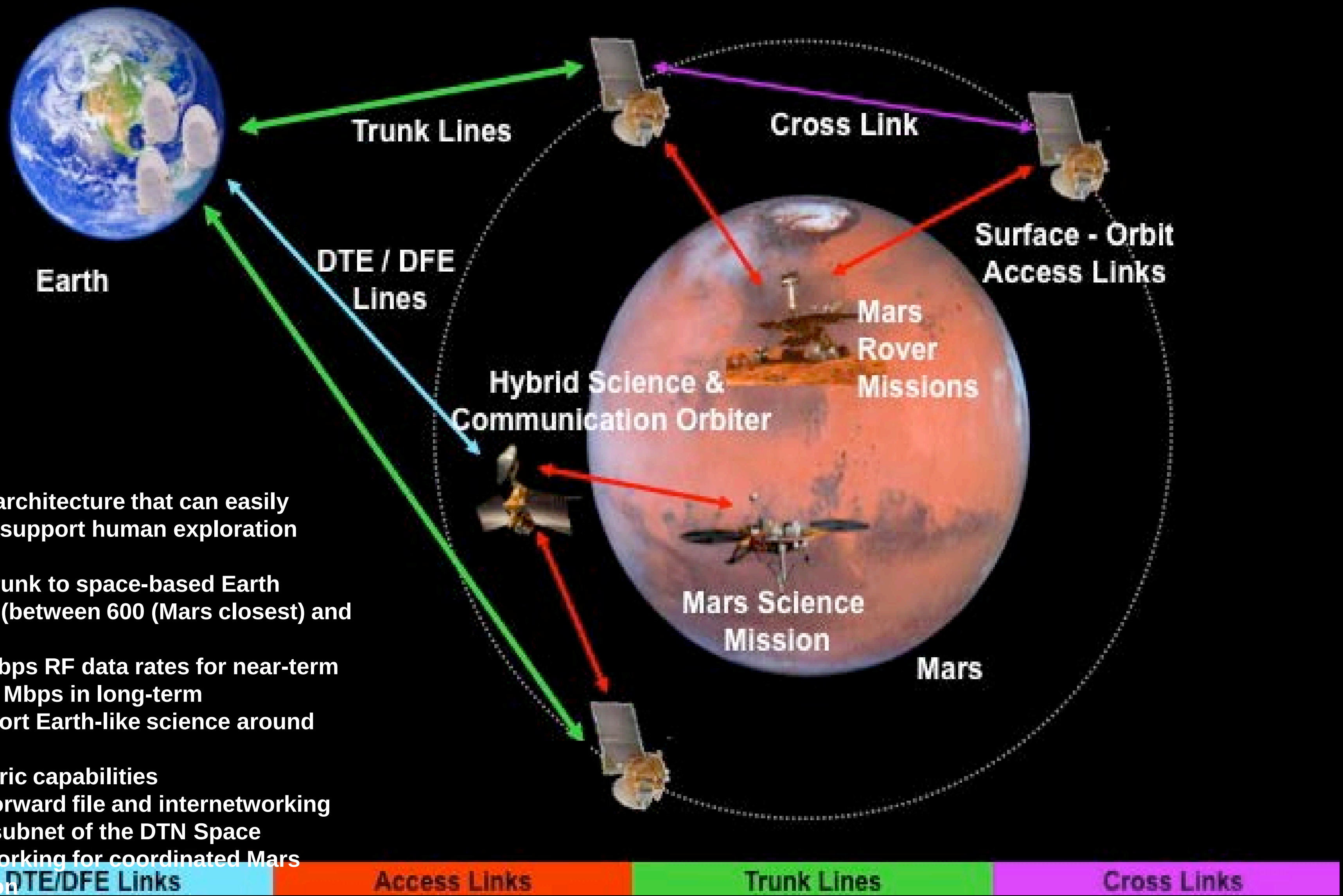


Lunar Network



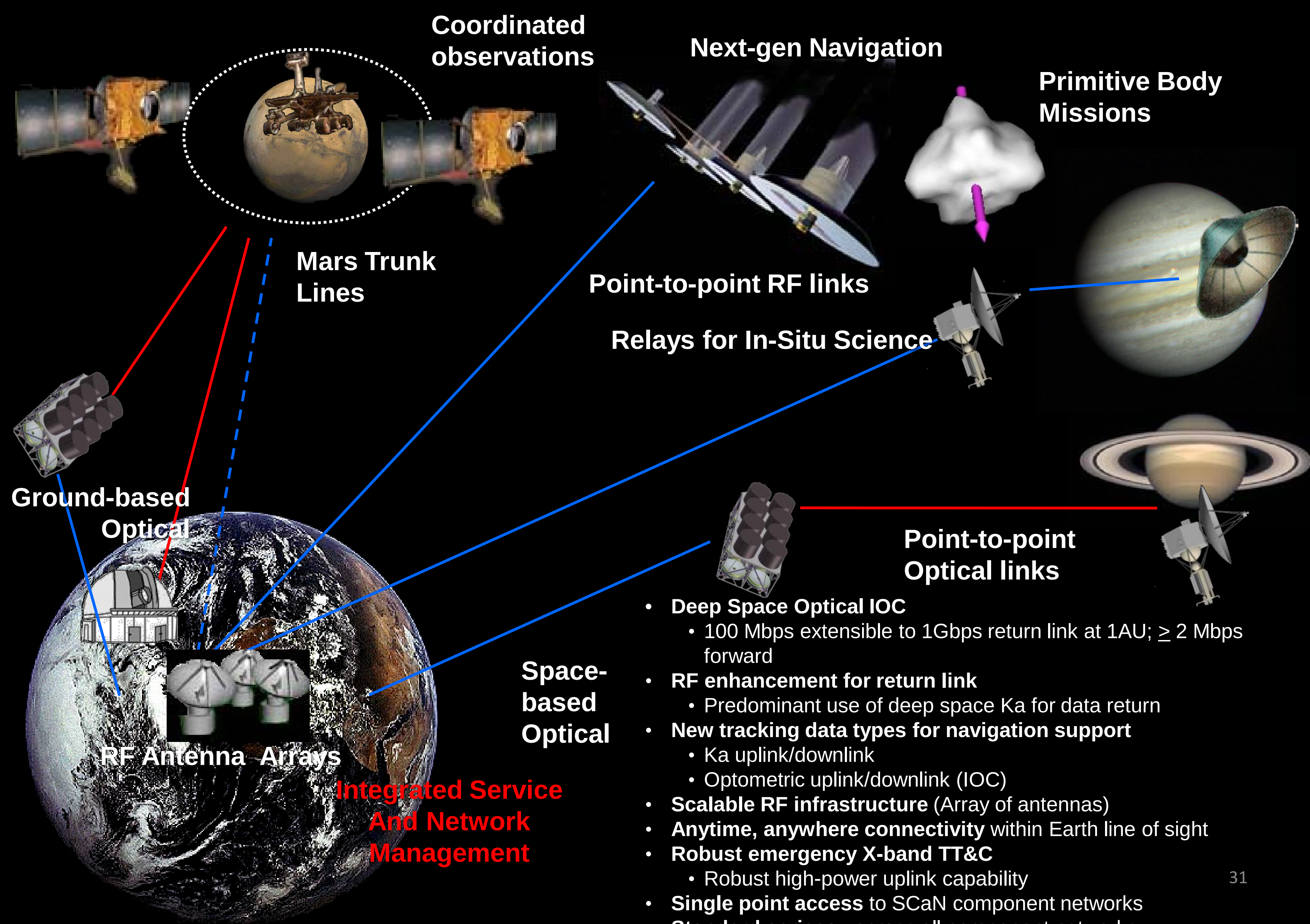
- Scalable architecture providing 76-100% coverage
- Over 1.2 Gbps optical link from the Moon; 20 Mbps uplink from Earth to the Moon
- 250 Mbps by RF links from the Moon
- Radiometric capabilities for precision approach, landing, and surface roving
- Space Internetworking

Mars Network



- Scalable architecture that can easily evolve to support human exploration phase
- Optical Trunk to space-based Earth receivers (between 600 (Mars closest) and 25 Mbps)
- Up to 2 Mbps RF data rates for near-term
- Up to 150 Mbps in long-term
- Can support Earth-like science around Mars
- Radiometric capabilities
- Store & forward file and internetworking
- Forms a subnet of the DTN Space Internetworking for coordinated Mars exploration

Enhanced Deep Space Domain Capability



- **Deep Space Optical IOC**
  - 100 Mbps extensible to 1Gbps return link at 1AU; $\geq$ 2 Mbps forward
- **RF enhancement for return link**
  - Predominant use of deep space Ka for data return
- **New tracking data types for navigation support**
  - Ka uplink/downlink
  - Optometric uplink/downlink (IOC)
- **Scalable RF infrastructure** (Array of antennas)
- **Anytime, anywhere connectivity** within Earth line of sight
- **Robust emergency X-band TT&C**
  - Robust high-power uplink capability
- **Single point access** to SCaN component networks